DEVELOPMENT OF A REGIONAL PAVEMENT PERFORMANCE DATABASE FOR THE AASHTO MECHANISTIC – EMPIRICLE PAVEMENT DESIGN GUIDE:

PART 1: SENSITIVITY ANALYSIS

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16. Abstract

Optimization of transportation facilities for capacity and pavement condition could be achieved with mechanistic analysis of pavement structures. This report is focused on using the AASHTO M-E Design Guide (MEPDG) to show the results of quantitative sensitivity analyses of typical pavement structures (rigid and flexible pavements) to highlight the main factors that affect pavement performance in terms of critical distresses and smoothness. The sensitivity analyses were conducted using the Mechanistic – Empirical Pavement Design Guide software (version 8.1). Pavement performance included specifically faulting, transverse cracking, and smoothness for rigid pavements. It also included smoothness, longitudinal cracking, alligator cracking, transverse cracking, and permanent deformation for flexible pavements. The input parameters that were varied included traffic variables (AADTT, speed, and wander) and pavement structure for selected rigid and flexible pavements. In addition, the binder grade was varied for the flexible pavements. Based on the sensitivity results, the input parameters were ranked and categorized from those to which pavement performance is most sensitive to least sensitive (or insensitive). The ranking should help pavement designers identify the level of importance for each input parameter and also identify the input parameters that can be modified to satisfy the predetermined pavement performance criteria. It is expected that ranking could also help planners to determine how traffic of heavy vehicles could be directed to enhance the service life of various sections of pavement network and to develop better maintenance strategies.

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Executive Summary

Optimization of transportation facilities for capacity and pavement condition could be achieved with mechanistic analysis of pavement structures. This report is focused on using the AASHTO M-E Design Guide (MEPDG) to show the results of quantitative sensitivity analyses of typical pavement structures (rigid and flexible pavements) to highlight the main factors that affect pavement performance in terms of critical distresses and smoothness. The sensitivity analyses were conducted using the Mechanistic – Empirical Pavement Design Guide software (version 8.1). Pavement performance included specifically faulting, transverse cracking, and smoothness for rigid pavements. It also included smoothness, longitudinal cracking, alligator cracking, transverse cracking, and permanent deformation for flexible pavements. The input parameters that were varied included traffic variables (AADTT, speed, and wander) and pavement structure for selected rigid and flexible pavements. In addition, the binder grade was varied for the flexible pavements. Based on the sensitivity results, the input parameters were ranked and categorized from those to which pavement performance is most sensitive to least sensitive (or insensitive). The ranking should help pavement designers identify the level of importance for each input parameter and also identify the input parameters that can be modified to satisfy the predetermined pavement performance criteria. It is expected that ranking could also help planners to determine how traffic of heavy vehicles could be directed to enhance the service life of various sections of pavement network and to develop better maintenance strategies.

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Chapter 1: Introduction

1.1 Background

The need for a mechanically based pavement design procedure has been recognized for a long time. A review of the literature indicates that, after the introduction of the first design guide in 1972 (1), the 1986 AASHTO Guide of Pavement Structures was introduced as a result of the wide realization of this need by pavement engineers.(2). The 1986 version was followed by the 1993 version in which rehabilitation designs were introduced as well as minor modification to the design procedures in general (3). Both versions, however, did not include a truly mechanistic procedure but mechanistic principals to modify the original empirical procedure were introduced. The original 1972 procedure was based on limited empirical performance equations developed at the AASHO Road Test conducted near Ottawa, Illinois, in the late 1950's (1). It was also recognized that since the time of the AASHO Road Test there have been many significant changes in trucks and truck volumes, materials, construction, rehabilitation, and design needs. These changes could not be dealt with through modifications of the procedure but required a significant, fundamental change in the design approach.

In March of 1996 the AASHTO Joint Task Force on Pavements, in cooperation with the NCHRP and FHWA, sponsored the "Workshop on Pavement Design". The workshop participants include many of the top pavement engineers in the United States. The group was asked to develop a plan for a new AASHTO mechanistic-empirical pavement design procedure by the year 2002. Based on the conclusions developed at the March 1996 meeting, NCHRP Project 1-37A (4), Development of the 2002 Guide for Design of New and Rehabilitated Pavement Structures was defined. The project called for the development of a guide that utilized existing mechanistic-based models and databases reflecting current state-of-the-art pavement design procedure. The guide was to address all new and rehabilitation design issues and provide an equitable design basis for all pavement types.

1.2 Objective of the new M-E Design Guide

The main objective of the Guide for the Mechanistic-Empirical Design of New and Rehabilitated Pavement Structures is to provide the highway community with a state-of-the-practice tool based on mechanistic-empirical principles. The guide was to be user-oriented computational software and documentation based on the Design Guide procedure. The Guide provides a framework for future continuous improvement to keep up with changes in trucking, materials, construction, design concepts, computers, and so on. In addition, guidelines for implementation and staff training are prepared to facilitate use of the new design procedure, and strategies to maximize acceptance by the transportation community have been developed.

1.3 Need for the Design Guide

As indicated earlier, the various versions of the empirical AASHTO Guides for Design of Pavement Structures, although have possibly served well for several decades; they suffer from many serious limitations. Some of the most important are:

- Traffic loading: Truck traffic design volume levels have increased tremendously (about 10 to 20 times) since the design of the pavements used in the Interstate system in the 1960’s. Thus designers often must extrapolate the design methodology far beyond the data and experience providing the basis for the procedure. Such practice of extrapolation may well have resulted in either “under-designed” or “over-designed” pavement sections, with the result of significant uncertainty.

- Rehabilitation deficiencies: None of the sections tested in the original AASHO Road Test included rehabilitated sections. In fact the first rehabilitation procedures were introduced in the 1993 Guide, which were completely empirical and very limited, especially in consideration of heavy traffic.
- Climatic effects deficiencies: The AASHO Road Test was conducted at one specific geographic location; therefore it is impossible to address the effects of different climatic conditions on pavement performance.
- Materials deficiencies: In the Original Road test only one hot mix asphalt (HMA) mixture, one Portland cement concrete (PCC) mixture, and two unbound dense granular base/subbase materials were used. Today, there exist many different hot mix asphalt concrete (HMAC) and PCC mixtures (e.g., Superpave, stone-mastic asphalt, high-strength PCC), and many types of modified base and subbase materials whose effects cannot be fully considered.
- Truck characterization deficiencies: Vehicle suspension, axle configurations, and tire types and pressures have changed significantly since the late 1950’s. The effect of new types are not fully understood and cannot be considered with the old design guides.

There are many other deficiencies that are not as important from a materials or mechanical point of view but reinforce the fact that a more comprehensive design approach that considers the modern conditions and is based on some fundamental theory is needed. These deficiencies are not new, they were realized in the mid 1980’s. However, it was understood that a high computing effort is needed which was not available at the time. Current technology has allowed for application of these concepts to be used for achieving better results.

1.4 Benefits of a Mechanistic-Empirical Procedure

Using a mechanistic procedure to analyze and design pavement structures is not a new topic and has been used for a long time (5). A number of softwares also existed since the early 1980's that were developed specifically for pavements (5). The most important benefits of the new design procedure are as follows:

1. The ability of direct incorporation of significant materials properties into the design procedure. In addition this Guide includes technology that directly considers aging of materials, month by month, over the design period.
2. The improved technology used by the Design Guide is expected to increase pavement life, resulting in economic benefits to highway agencies (lower facility construction and rehabilitation costs) and highway users (reduced delay time and costs due to longer time periods between lane closures required for rehabilitation). Based on the Long Term Pavement Performance Project results, a conservative estimate is that a reduction in life cycle costs to State highway agencies of at least 5 percent and perhaps twice as much if full implementation could be realized. There could also be very significant economic benefits to the traveling public due to reduced maintenance and rehabilitation activities that require lane closures.
3. The consequence of new loading conditions, such as the use of Super-single tires or high tire pressures can be evaluated very precisely with mechanistic procedure.

4. Improved procedures to evaluate premature distress can be developed, and it is possible to analyze why some pavements exceed their design expectations. In effect, better diagnostic techniques can be utilized.

5. One of the most important features of the new design guide is the hierarchical approach to design inputs. This approach provides the designer with flexibility in obtaining the design inputs for a design project based on the criticality of the project and the available resources. The approach is employed with regard to traffic, materials, and environmental inputs. In general, three levels of inputs are provided. Due to the importance of this procedure, the details are explained in the following section.

1.5 Hierarchical Design Inputs

There are 3 levels of design that can be conducted with the design guide. The following details for each level are copied from the design guide web site (4):

Level 1: input provides for the highest level of accuracy and, thus, would have the lowest level of uncertainty or error. Level 1 inputs would typically be used for designing heavily trafficked pavements or wherever there are dire safety or economic consequences of early failure. Level 1 material inputs require laboratory or field testing, such as the dynamic modulus testing of hot-mix asphalt concrete, site-specific axle load spectra data collections, or nondestructive deflection testing. Obtaining Level 1 inputs requires more resources and time than other levels.

Level 2 inputs provide an intermediate level of accuracy and would be closest to the typical procedures used with earlier editions of the AASHTO Guide. This level could be used when resources or testing equipment are not available for tests required for Level 1. Level 2 inputs typically would be user-selected, possibly from an agency database, could be derived from a limited testing program, or could be estimated through correlations. Examples would be estimating asphalt concrete dynamic modulus from binder, aggregate, and mix properties, estimating Portland cement concrete elastic moduli from compressive strength tests, or using site-specific traffic volume and traffic classification data in conjunction with agency-specific axle load spectra.

Level 3 inputs provide the lowest level of accuracy. This level might be used for a design where there are minimal consequences of early failure (e.g., lower volume roads). Inputs typically would be user-selected values or typical averages for the region. Examples include default unbound materials resilient modulus values or default Portland cement concrete coefficient of thermal expansion for a given mix classes and aggregates used by an agency.

As indicated in the Guide, for a given design project, inputs may be obtained using a mix of levels, such as concrete modulus of rupture from Level 1, traffic load spectra from Level 2, and subgrade resilient modulus from Level 3. In addition, it is important to realize that no matter what input design levels are used the computational algorithm for damage is exactly the same. The same models and procedures are used to predict distress and smoothness no matter what levels are used to obtain the design inputs.

1.6 Objectives and Scope of the Project

The main objectives of the project were defined after significant discussion with WisDOT pavement design experts and review of several studies conducted recently to implement the new design guide (6-11):

1) Sensitivity analysis of design outcomes to input variables.
2) Development of a Midwest regional pavement database for calibrating design factors in the new M-E Design Guide (separate report).
3) Establishment of a new set of field calibration factors for distress models of the design guide for both rigid and flexible pavements (separate report).

The first objective is focused on using the M-E Design Guide to show how traffic volumes and traffic loadings can be optimized for better overall pavement management. It is intended to show designers and planners what happens in pavements when traffic volumes, traffic speeds, and total transported loads change. To meet this objective the project includes a quantitative sensitivity analysis of typical pavement structures (rigid and flexible pavements) to highlight the main factors that affect pavement ability to carry traffic. The sensitivity analyses were conducted using the Mechanistic – Empirical Pavement Design Guide software to show the relationship between traffic and structural design inputs on estimated pavement performance. Pavement performance included specifically faulting, transverse cracking, and smoothness for rigid pavements. It also included smoothness, longitudinal cracking, alligator cracking, transverse cracking, and permanent deformation for flexible pavements. Based on the sensitivity results, the input parameters were ranked and categorized from those to which performance is most sensitive to insensitive. It is expected that ranking could also help planners to determine how traffic of heavy vehicles could be directed to enhance the service life and ensure better maintenance strategies.

The other objectives include developing a pavement database for M-E design guide and evaluating the calibration factors of the M-E design models for the Midwest region. The state highway agencies in Midwest region were contacted and requested to provide their pavement data including materials, structures and performance. The calibration factors in the software, M-E PDG are evaluated and, if necessary, adjusted for the Midwest region. The report of pavement database and validation of local calibration is documented separately in a report titled “Development of Regional Pavement Performance Database: Part 2 Validation and Local Calibration”.

Chapter 2: Design Criteria and Design Inputs

2.1 MEPDG Design Criteria

The design guide requires forecasting inputs such as climate and traffic growth for a long future period. It is therefore recognized that there is a high level of uncertainty due to the inherent variability in these factors and lack of reliable predictions of these variables. The results are essentially high uncertainty in the pavement design and construction processes (NCHRP 2004). It is however necessary to accept this variability and consider it in reliability factors integrated in the design criteria.

The criteria is based on a consideration of the combined effect of pavement distresses on the smoothness (comfort ride) of the pavement. The key outputs of the design guide are the individual distress quantities and the overall performance. For rigid pavements, MEPDG analysis predicts distresses, such as faulting, transverse cracking, and then calculates smoothness (IRI). For flexible pavements, MEPDG analysis predicts distresses, such as IRI, longitudinal cracking, alligator cracking, transverse cracking and permanent deformation. Due to uncertainty in predicting distresses, a reliability term has been incorporated in MEPDG to come up with an analytical solution, which allows the designer to design a pavement with an acceptable level of distress at the end of design life. Design reliability is defined as the probability that each of the key distress types and smoothness will be less than a critical level over the design period. Therefore, failure criteria are associated with this design reliability. The failure criteria and design reliability are also required inputs for the MEPDG analysis; although, the designer and the agency have the control over these values.

2.2 General MEPDG Input Parameters

The design guide requires a detailed list of design inputs that are used to calculate engineering stresses and strains at daily and seasonal conditions of traffic and climate. These engineering parameters are then used to estimate distresses based on material properties and pavement structure. The number of inputs are therefore very large and require careful planning for collecting and updating them continuously so that design output reliability is enhanced. The following sections give a simple listing of the variables that were used in the sensitivity analysis of this report. Many default values were used because of the lack of information about detailed specific information for the sections used in the analysis.

Three rigid and two flexible pavement structures were considered in this study. The rigid pavements include:

1. Middleton Bypass located in Middleton, WI (Conventional Rigid Pavement);
2. New JPCP (Stabilized Base) in Arkansas;
3. An overlay of JPCP on JPCP in Missouri.

The two flexible pavements include:

1. Middleton Bypass on US-12(Conventional Flexible Pavement);
2. An Overlay of HMA on HMA

The following tables give the details of the rigid and flexible pavements used in the analysis.

Table 2.1: Summary of the Structure for the Three Rigid Pavements

Pavement Section		Conventional	Stabilized Base	Overlay JPCP over JPCP
Design Life		30 yrs	30yrs	20yrs
Construction Year		Sep 2003	Oct 1995	Oct 1974 Overlay: Sep 1991
Surface	Type Thickness	JPCP 10.0	JPCP 8.2	JPCP ; AC 10.0 ; 2.0
Base	Type Thickness	A-1-a 3.0	Cement Stab. 6.4	JPCP (existing) 9.9
Subbase	Type Thickness	Crushed Gravel 8.0	A-1-a 4.0	Crushed Stone 4.0
Subgrade	Type	SP	A-2-4	A-6

Table 2. 2: Summary for Flexible Pavements

Pavement Section		Conventional	Overlay HMA over HMA
Design Life		20 yrs	15 yrs
Construction Year		Sep 2003	Sep 1980 Overlay: Sep 2002
Surface	Type Thickness	AC 10.0	AC 7.0
Base	Type Thickness	A-1-a 12.0	AC (existing) 5.0
Subbase	Type Thickness	Crushed Stone 15.0	Crushed Gravel 5.0
Subgrade	Type	SP	A-6

The pavement sections were analyzed using the MEPG software by varying one input parameter at a time within its ranges holding other parameters constant. The objective of these analyses was to determine the individual effects of each input parameter on the critical pavement performance using the MEPDG software.

2.3 Traffic Input Design Parameters

2.3.1 Rigid Pavements

To investigate the effect of a particular pavement input parameter, the other input parameters are held constant. The design input parameters were divided into two groups: fixed input parameters and varied input parameters. While one design parameter was being examined, a standard value was assigned for the other design parameters. The ranges of magnitude for the varied input parameters were selected based on the recommendations of MEPDG and engineering judgment. Climate and structure input parameters are kept constant while traffic input parameters are varied.

Four traffic input parameters (AADTT, % Trucks, Traffic SD, Operational Speed) are varied within the ranges of magnitude as per the recommendation of MEPDG and engineering judgment. Tables 2.3 and 2.4 show the fixed traffic input parameters for conventional, stabilized base and overlay pavement sections separately.

Table 2. 3: Fixed Traffic Input Parameters – Rigid Pavement

Fixed Input Parameter	Conventional	Stabilized Base	Overlay JPCP over JPCP
Traffic General			
No. of lanes in design direction	2	2	2
% of trucks in design direction (%)	50	50	50
Traffic Volume Adjustment Factors			
Hourly truck distribution	Default	Default	Default
Traffic growth factor	1.5%	1.5%	5%
Axle load distribution factors	Default	Default	Default
General Traffic Inputs			
Mean wheel location(in)	18	18	18
Design lane width(ft)	12	12	12
Axle Configuration			
Average axle width(ft)	8.5	8.5	8.5
Dual tire spacing(in)	12	12	12
Axle Spacing – Tandem, Tridem, Quad	51.6,49.2,49.2	51.6,49.2,49.2	51.6,49.2,49.2
Tire Pressure(psi)—Single and Dual tire	120, 120	120, 120	120, 120

The vehicle class distribution for the three pavement sections is shown in Table 2.4.

Table 2. 4: Vehicle Class Distributions (fixed input parameters) – Rigid Pavement

Vehicle Class	Conventional	Stabilized Base	Overlay JPCP
Class 4	4.4	1.8	4.4
Class 5	31.6	24.6	31.6
Class 6	9.1	7.6	9.1
Class 7	0.4	0.5	0.4
Class 8	8.8	5.0	8.8
Class 9	39.3	31.3	39.3
Class 10	1.7	9.8	1.7
Class 11	3.8	0.8	3.8
Class 12	0.7	3.3	0.7
Class 13	0.2	15.3	0.2

The traffic input parameters for the conventional, stabilized base and overlay rigid pavements that were varied for the sensitivity analyses was performed is shown in Table 2.5.

Table 2. 5: Traffic Input Parameters that were Varied

Traffic Input Parameter	Conventional	Stab. Base	Overlay
Traffic General			
Initial two-way AADTT	1178	1500	3900
Operational Speed(mph)	90	60	60
% of trucks in design lane	75	95	100
General Traffic Input			
Traffic Wander S.D (in)	10	10	10

2.3.2 Flexible Pavements:

Two flexible pavements were considered for the analysis. For traffic sensitivity, four traffic input parameters (AADTT, % Trucks, Traffic SD, Operational Speed) are varied within the ranges of magnitude as per the recommendation of MEPDG and engineering judgment. Tables 2.6 and 2.7 show the fixed traffic input parameters for conventional and overlay pavement sections separately.

Table 2. 6: Fixed Traffic Input Parameters – Flexible Pavement

Fixed Input Parameter	Conventional	Overlay HMA over HMA
Traffic General		
No. of lanes in design direction	2	2
% of trucks in design direction (%)	50	50
Traffic Volume Adjustment Factors		
Hourly truck distribution	Default	Default
Traffic growth factor	1.5%	4%
Axle load distribution factors	Default	Default
General Traffic Inputs		
Mean wheel location(in)	18	18
Design lane width(ft)	12	12
Axle Configuration		
Average axle width(ft)	8.5	8.5
Dual tire spacing(in)	12	12
Axle Spacing – Tandem, Tridem, Quad	51.6,49.2,49.2	51.6,49.2,49.2
Tire Pressure(psi)—Single and Dual tire	120, 120	120, 120

Table 2.7: Vehicle Class Distributions (fixed input parameters) – Flexible Pavement

Vehicle Class	Conventional	Overlay HMA over HMA
Class 4	4.4	1.8
Class 5	31.6	24.6
Class 6	9.1	7.6
Class 7	0.4	0.5
Class 8	8.8	5.0
Class 9	39.3	31.3
Class 10	1.7	9.8
Class 11	3.8	0.8
Class 12	0.7	3.3
Class 13	0.2	15.3

The traffic input parameters for the conventional and overlay flexible pavements that were varied and on which the sensitivity analyses was performed is shown in Table 2.8.

Table 2. 8: Traffic Input Parameters That were Varied – Flexible Pavement

Traffic Input Parameter	Conventional	Overlay HMA over HMA
Traffic General		
Initial two-way AADTT	1178	2000
Operational Speed(mph)	90	60
% of trucks in design lane	75	95
General Traffic Input		
Traffic Wander S.D (in)	10	10

2.4 Pavement Structure Input Variables

The values for the varied traffic parameters used in the analysis, and the pavement structure that were defined by the pavement designers are shown in Table 2.9 and Table 2.10, for the rigid and flexible pavement sections respectively.

Table 2. 9: Pavement Structure Input Parameters of the Rigid Pavement Sections

Conventional Pavement		**Stabilized Base**		**Overlay**	
Structure		**Structure**		**Structure**	
Layer 1: JPCP	9.0"	Layer 1: JPCP	8.2"	Layer 1: JPCP	10.0"
Layer 2: A-1-a	3.0"	Layer 2: Cement Stabilized	6.4"	Layer 2: Asphalt Concrete	2.0"
Layer 3: Crushed Gravel	8.0"	Layer 3: A-1-a	4.0"	Layer 3: JPCP (existing)	9.9"
Later 4: SP	NA	Layer 4: A-2-4	NA	Layer 4: Crushed Stone	4.0"
				Layer 5: A-6	NA

Table 2.10: Pavement Structure Input Parameters of the Flexible Pavement Sections.

Conventional Pavement		**Overlay**	
Structure		**Structure**	
Layer 1: Asphalt Concrete	10.0”	Layer 1: Asphalt Concrete	4.0”
Layer 2: A-1-a	12.0”	Layer 2:Asphalt Concrete(existing)	5.0”
Layer 3: Crushed Stone	15.0”	Layer 3: Crushed Stone	7.4”
Layer 4: SP	NA	Layer 4: A-6	12.0”
		Layer 5: A-7-5	NA

The tables listed above give an idea about how detailed th input required for the design guide is. It is also clear that the sensitivity analysis is very challenging since many of these variables can have interactive effects on calculating the sensitivity of pavement performance to varying any of the variables. The variables that were varied in this study were selected based on detailed review of the literature and an evaluation of variables that are most likely to be changed in designs in Wisconsin.

Chapter 3: **Sensitivity Analysis**

3.1 Effect of Traffic Variables

In the analysis for effect of traffic variables, climate and structure are kept fixed for all sections. Four input parameters of traffic i.e., Annual Average Daily Truck Traffic, Percent of Trucks in the Design Lane, Operational Speed and Traffic Wander Standard Deviation were varied while the rest of traffic inputs were kept fixed. The ranges of magnitude for the varied input parameters were selected based on the recommendations of MEPDG and experts in the pavement section of Wisconsin DOT.

To define the level of sensitivity of pavement performance to each of the traffic parameters, a ratio was used to determine the relative change in a response parameter relative to the total range used in the MEPDG. Depending on the value of the ratio the level of sensitivity is defined as shown in Table 3.1.

$$Ratio = \frac{Maximum\ Value\ of\ \ Range - Minimum\ Value\ of\ \ Range}{Target\ change} * 100$$

Table 3. 1: Sensitivity Level Definition

Sensitivity Level	Abbreviation	Ratio (%)
Very Sensitive	VS	>50%
Sensitive	S	25%-50%
Insensitive	I	<25%

As an example of the sensitivity analysis Table 3.2 shows the results for the three main performance indicators (IRI(in/mi), % Cracking, and Faulting(in)) as a result of changing the Average Annual Daily Truck Traffic (AADTT) for the conventional rigid pavement.

Table 3. 2: Sensitivity of Performance Indicators of Rigid Pavement to changes in AADTT.

AADTT	IRI(in/mi)	% Cracking	Faulting(in)
Distress Target Limit	<172	<15	< 0.12
1000	77.6	0.3	0.004
2500	82.4	1.4	0.012
5000	90.7	4.4	0.023
10000	107.8	13.1	0.042

$$Ratio = \frac{107.8 - 77.6}{172 - 0} * 100 = 17.5\% \,(Insensitive)$$

Table 3.3 shows a similar example for the conventional flexible pavement. In this case the performance indicators include IRI, longitudinal cracking (L/C)(%), alligator cracking (A/C)(%), transverse cracking (T/C)(%), and permanent deformation (P/D)(in) in the top pavement layer.

Table 3. 3: Sensitivity of Flexible Pavement Performance to changes in AADTT

AADTT	IRI (in/mi)	L/C (ft/500)	A/C (%)	T/C (ft/mi)	PD(AC)(in)	PD(TP)(in)
Distress Target Limit	< 172	< 1000	< 25	< 1000	< 0.25	< 0.75
1000	139.4	25.2	0.1	1	0.12	0.27
2500	139.4	101	0.4	1	0.19	0.35
5000	139.6	284	0.8	1	0.27	0.44
10000	139.9	905	1.9	1	0.39	0.57

Using the sensitivity criterion the MEPDG was used to calculate the changes in all performance indicators and to determine their sensitivity to changes in traffic conditions. Table 3.4 and Table 3.5 show the traffic & structure information, and the sensitivity analysis results of the rigid pavements and the flexible pavements, respectively.

Table 3. 4: Sensitivity Analysis Results of the Three Rigid Pavement Sections.

Conventional				
	Investigated Values	**IRI**	**Cracking**	**Faulting**
AADTT	1000, 2500, 5000,10000	S	VS	S
% Trucks	65, 75, 85, 95	I	I	I
Traffic SD	7, 9, 11, 13	I	I	I
Op. Speed	45, 60, 75, 90	I	I	I
Stabilized Base				
	Investigated Values	**IRI**	**Cracking**	**Faulting**
AADTT	1000, 2500, 5000,10000	VS	VS	VS
% Trucks	65, 75, 85, 95	I	I	I
Traffic SD	7, 9, 11, 13	I	S	I
Op. Speed	45, 60, 75, 90	I	I	I
Overlay				
	Investigated Values	**IRI**	**Cracking**	**Faulting**
AADTT	1000, 2500, 5000,10000	VS	VS	VS
% Trucks	65, 75, 85, 95	I	S	I
Traffic SD	7, 9, 11, 13	I	S	I
Op. Speed	45, 60, 75, 90	I	I	I

Note: VS - Very Sensitive, S – Sensitive, I – Insensitive.

Table 3. 5: Sensitivity Analysis Results of the Flexible Pavements

Conventional							
	Investigated Values	**IRI**	**L/C**	**A/C**	**T/C**	**P.D(AC)**	**P.D(TP)**
AADTT	1000, 2500, 5000,10000	I	VS	I	I	VS	S
% Trucks	65, 75, 85, 95	I	I	I	I	I	I
Traffic SD	7, 9, 11, 13	I	I	I	I	I	I
Op. Speed	45, 60, 75, 90	I	I	I	I	I	I
Overlay							
	Investigated Values	**IRI**	**L/C**	**A/C**	**T/C**	**P.D(AC)**	**P.D(TP)**
AADTT	1000, 2500, 5000,10000	I	S	I	I	VS	VS
% Trucks	65, 75, 85, 95	I	I	I	I	I	I
Traffic SD	7, 9, 11, 13	I	I	I	I	VS	I
Op. Speed	45, 60, 75, 90	I	I	I	I	VS	I

Note: VS – Very Sensitive, S – Sensitive, I – Insensitive.

From the sensitivity results and for the above investigated values, it can be seen that for rigid pavements the IRI, Cracking and Faulting are most sensitive to AADTT. It is also observed that Cracking is most sensitive to the % Trucks and Traffic Wander Standard Deviation. None of the rigid pavement performance indicators are sensitive to the Operational Speed. The results of the flexible pavements (Table 15) show that IRI, A/C, and T/C are not sensitive to any of the input traffic parameters. It is however observed that L/C (%), P.D is sensitive or very sensitive to AADTT. Also P.D for the overlay is sensitive to Traffic SD and to Op. Speed (mph).

3.2 Effect of Pavement Structure

The results of the sensitivity analysis for traffic inputs were not expected and somewhat not clear since most of the performance measures were not found to be sensitive to traffic input changes. One possible explanation is that the pavement sections selected are over designed for the traffic inputs. To further study sensitivity to traffic conditions, the thickness of the top layer of rigid and flexible pavements was varied for both the rigid and flexible pavements. Only two traffic variables (AADTT and Operational Speed) were also varied for all layer thicknesses considered. Figure 3.1 depicts the results for the rigid pavement conventional section. Some interesting trends are observed.

- It can be seen that IRI is very sensitive to layer thickness. For example, a 2”increase in the pavement thickness (From 8”to 10”) would allow increasing traffic from 2000 to 20000 AADTT while keeping the terminal IRI at 200. This is a 10 folds increase in traffic by only a 2” increase in thickness. This type of analysis would allow planners to predict how much more truck traffic can be added without deteriorating the smoothness of pavements.
- Similar trends can be observed for faulting. The trends for cracking, on the other hand show a slightly different relationships. The change from 8” and 10” pavements are not important when AADTT is above the value of 10000.

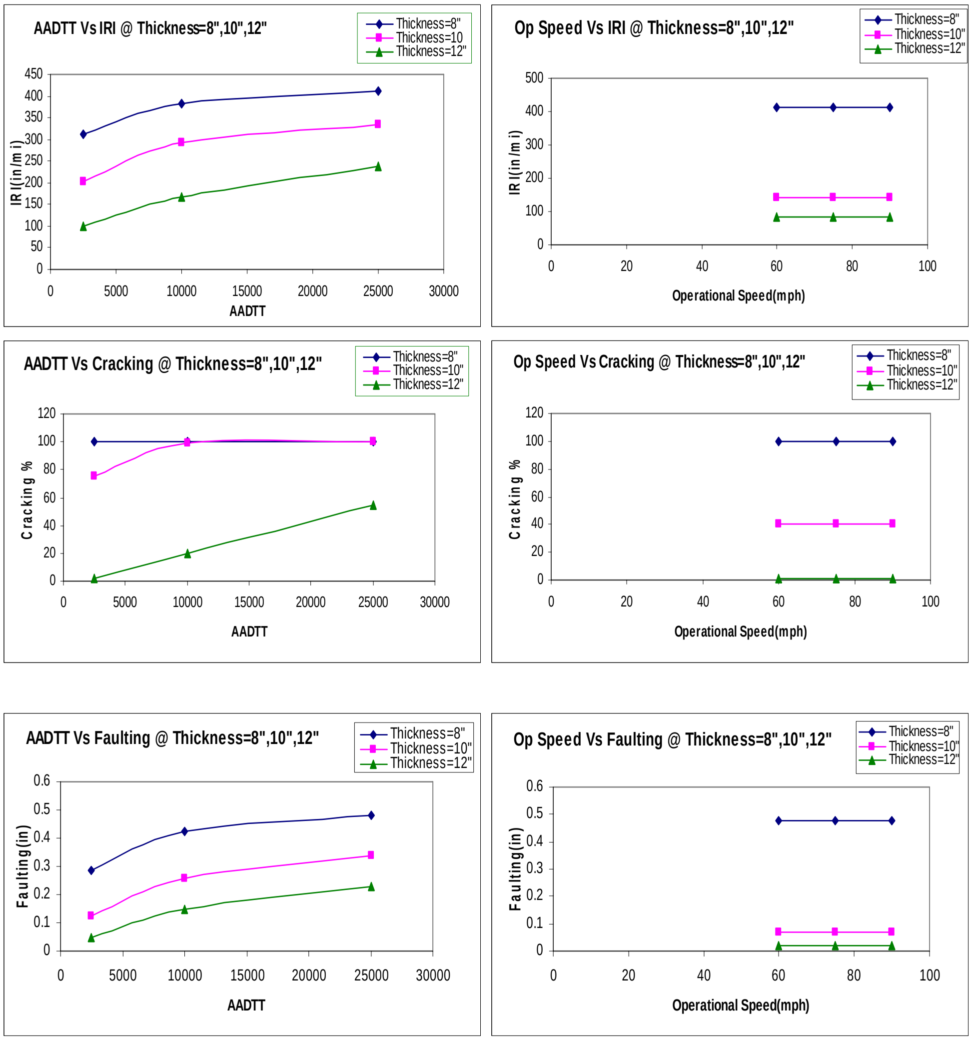

Figure 3. 1: Results of Sensitivity Analysis of Rigid Pavements

Observing the plots for the effects of Operational Speed, it can be seen that there is no effect on any of the performance indicators regardless of the thickness of the layer. It is shown that the terminal IRI, faulting and cracking are highly affected by thickness but not by the operational speed.

The results for flexible pavements are shown in Figure 2. They indicate:

- IRI and PD are sensitive to AADTT only for the thin layer (4”). In the case of 6”and 8” pavement layer, there appears to be very little effect of increasing traffic or increasing traffic speed.

- Fatigue cracking (A/C) (%) is also very sensitive to AADTT but it is not as sensitive to traffic speed. The sensitivity is similar for all layer thicknesses.
- Rutting in the asphalt layer is also very sensitive to AADTT. It is also affected by traffic speed. Rutting estimated at 20 miles per hour for a 6.0” layer s equivalent to rutting of a 4.0” layer at 90 miles per hour.

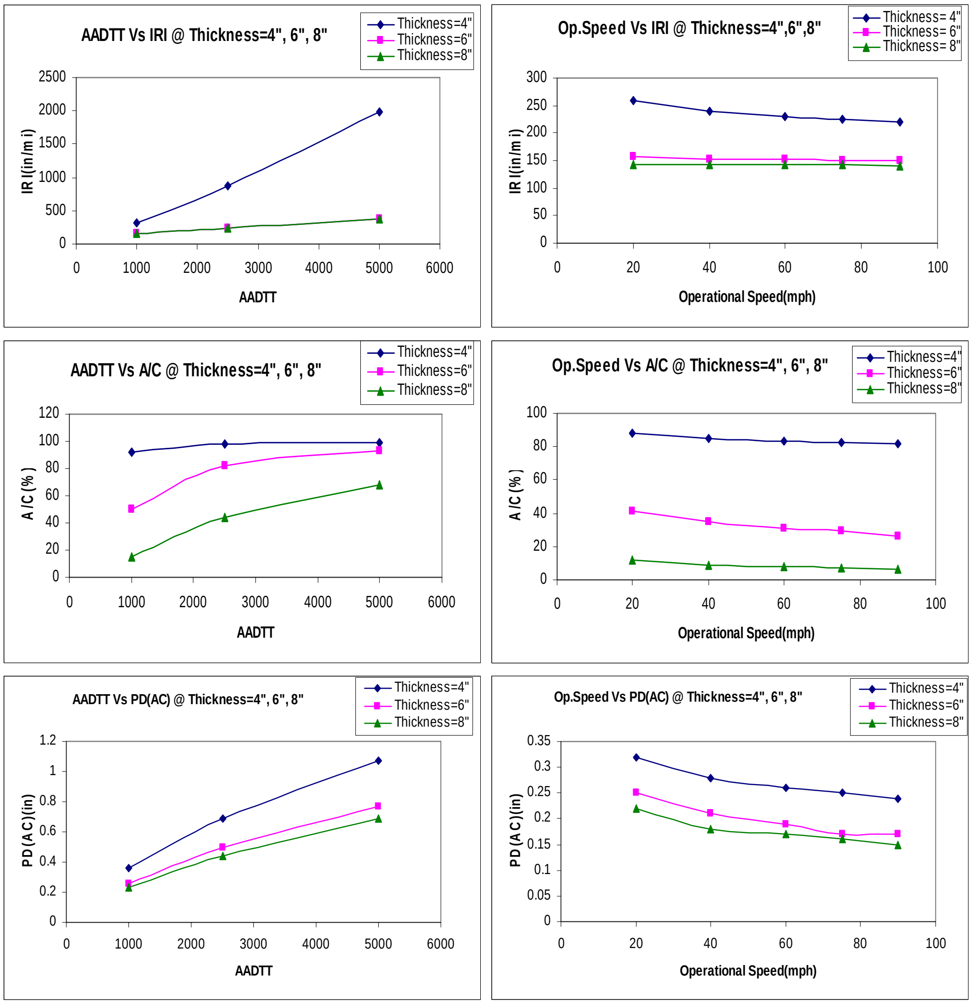

Figure 3. 2: Results of Sensitivity Analysis of Flexible Pavements

3.3 Sensitivity Results for the Structure Design Input Parameters

Based on the preliminary graphical analysis shown in the previous section it was clear that pavement structure can have a major confounding effect on the sensitivity analysis. It was therefore decided to quantify the sensitivity by using selected input parameters for the rigid and the flexible pavements

3.3.1 Rigid Pavements

The variables changed included thickness of Layer 1, materials used for Layer 2 and Layer 3(Base and Subbase), Joint Spacing, Dowel Diameter, and the Coefficient of Thermal Expansion. These were varied while the rest of structure inputs were held fixed. The ranges of values for these input parameters were selected based on the recommendations of MEPDG for the default values and opinion of experts in the pavement section of WisDOT. Sensitivity analyses of pavement performance indicators for each structure input parameter were performed while holding all other parameters constant. Table 3.6 shows the base values that were used as input parameters for the three concrete (rigid) pavements (conventional, stabilized base and overlay pavement sections). These base values were kept constant while each one was varied . For example if the thickness of layer one was varied the rest of the variables were kept constant at the values shown in the table.

Table 3. 6: The Base Input Parameters Used in the Analysis – Rigid Pavement

Varied Input Parameter	Middleton	Stabilized Base	Overlay
Layer 1	JPCP	JPCP	JPCP
Thickness	10”	8.2”	10”
Layer 2	A-1-a	Cement Stabilized	Asphalt Concrete
Thickness	3”	6.4”	2”
Layer 3	Crushed Gravel	A-1-a	JPCP(existing)
Thickness	8”	4”	9.9”
Layer 4	SP	A-2-4	Crushed Stone
Thickness	NA	NA	4”
Layer 5	-	-	A-6
Thickness	-	-	NA
Joint Spacing	15’	15’	15’
Dowel Diameter	1.5”	1.5”	1.125”
Coeff of Thermal Expansion	5.2 per F*10^-6	5.6 per F*10^-6	5.5 per F*10^-6

3.3.2: Flexible Pavements

For flexible pavements, both the conventional and the overlay were analyzed using the same procedure. The base values that were kept constant while one is varied is shown in Table 3.7. The thickness of Layer1, materials used for Layer 2 and Layer 3(Base and Subbase) were varied while the rest of structure inputs were held fixed. The ranges of values for the input parameters that were varied were selected based on the recommendations of MEPDG and opinions of experts in the pavement section of WisDOT.

Table 3. 7: The Base Structure Input Parameters – Flexible Pavement Structure

Varied Input Parameter	Conventional	Overlay
Layer 1	Asphalt Concrete	Asphalt Concrete
Thickness	10”	4”
Layer 2	A-1-a	Asphalt Concrete(existing)
Thickness	12”	5”
Layer 3	Crushed Stone	Crushed Stone
Thickness	15”	7.4”
Layer 4	SP	A-6
Thickness	NA	1”
Layer 5	-	A-7-5
Thickness	-	NA
PG Binder	70-22	64-22

3.4 Rigid Pavement Structure Variation

For the rigid pavement analysis all 3 structures were included in the analysis. The variables changed included thickness of Layer 1, materials used for Layer 2 and Layer 3(Base and Subbase), Joint Spacing, Dowel Diameter, and the Coefficient of Thermal Expansion were varied while the rest of structure inputs were held fixed. The ranges of values for these input parameters were selected based on the recommendations of MEPDG and experts in the pavement section of WisDOT. Sensitivity of pavement performance indicators for each structure input parameter was performed holding all other parameters constant.

The same procedure for defining the level of sensitivity of pavement performance to each of the variables that was used in the traffic analysis was used for pavement structure. The ratio of the relative change in a response parameter relative to the total range selected for the analysis was used. Depending on the value of the ratio the level of sensitivity is defined as shown in Table 3.8.

$$Ratio = \frac{Maximum\ Value\ of\ Range - Minimum\ Value\ of\ Range}{Target\ change} * 100$$

Table 3. 8: Sensitivity Level Definition

Sensitivity Level	**Abbreviation**	**Ratio (%)**
Very Sensitive	VS	>50%
Sensitive	S	25%-50%
Insensitive	I	<25%

As an example, Table 3.9 shows the sensitivity of Layer 1 Thickness to the rigid pavement distress criteria while holding the other parameters constant.

Table 3. 9: Example of Determining Sensitivity for Layer 1 Thickness

L 1 Thickness(in)	IRI(in/mi)	% Cracking	Faulting(in)
Distress Target	172	15	0.12
8	119.3	30.1	0.032
10	79.9	0.8	0.008
12	76.2	0	0.006

$$Ratio = \frac{30.1 - 0}{15 - 0} * 100 = 200\% \text{ (Very Sensitive)}$$

The complete results of the analysis for rigid pavements are shown in Tables 3.10, 3.11 and 3.12. The complete set of values are listed in Appendix A of the report. These tables show the sensitivity analysis of performance indicators (IRI, Cracking, and Faulting) to the structure input parameters for three rigid pavement structures used. The structures included a conventional pavement, Stabilized Base, and an overlay.

Table 3. 10: Conventional Rigid Pavement Structure Sensitivity

	Investigated Values	IRI	Cracking	Faulting
L 1 Thickness	8", 10",12"	S	VS	I
L 2 (Cr. Stone)	3", 6",9"	I	I	I
L 2 (Cr. Gravel))	3", 6",9"	I	I	I
L 2 (A-1-b)	3", 6",9"	I	I	I
L 3 (Cr. Gravel)	10", 15", 20"	I	I	I
L 3 (Cr. Stone)	10", 15", 20"	I	I	I
Joint Spacing	15', 18'	I	VS	I
Dowel Diameter	1.25", 1.5"	I	I	I
Coeff of Thermal Exp. (per F*10^-6)	2.5, 7.5, 10	VS	VS	VS

Note: VS – Very Sensitive; S – Sensitive; I – Insensitive

Table 3. 11: Stabilized Base Pavement Structure Sensitivity

	Investigated Values	IRI	Cracking	Faulting
L 1 Thickness	8", 10", 12"	I	S	I
L 2 (Lime Stab)	3", 6", 9"	I	I	I
L 2 (Soil Cement)	3", 6", 9"	I	I	I
L 2 (Lime C. F. A)	3", 6", 9"	I	I	I
L 3 (Cr. Gravel)	10", 15", 20"	I	I	I
L 3 (Cr. Stone)	10", 15", 20"	I	I	I
Joint Spacing	15', 18'	I	VS	I
Dowel Diameter	1.25", 1.5"	I	I	I
Coeff of Thermal Exp. (per F*10^-6)	2.5, 7.5, 10	VS	VS	VS

Note: VS – Very Sensitive; S – Sensitive; I – Insensitive

Table 3. 12: Overlay JPCP over JPCP Structure Sensitivity

	Investigated Values	IRI	Cracking	Faulting
L 1 Thickness	8", 10", 12"	I	S	I
L 2 (Asp Concrete)	3", 6", 9"	I	I	I
L 2 (Asp Perm Base)	3", 6", 9"	I	I	I
L 3 (Cement Stab)	10", 15", 20"	I	VS	S
L 3 (Lime Stab)	10", 15", 20"	I	VS	S
L 3 (Soil Cement)	10", 15", 20"	I	VS	S
L 4 (Cr. Gravel)	6", 8",10"	I	I	I
L 4 (A-1-a)	6", 8",10"	I	I	I
Joint Spacing	15', 18'	I	VS	I
Dowel Diameter	1.25", 1.5"	I	I	I
Coeff of Thermal Exp. (per F*10^-6)	2.5, 5, 7.5, 10	VS	VS	VS

Note: VS – Very Sensitive; S – Sensitive; I – Insensitive

From the sensitivity results, for the above investigated values, it can be seen that for rigid pavements the IRI, Cracking and Faulting are most sensitive to Coefficient of Thermal Expansion. It is also observed that Cracking is most sensitive to the Joint Spacing and JPCP layer thickness for the conventional and stabilized base pavements. Also it is observed that Cracking is most sensitive to Joint Spacing and Subbase layer thickness for the overlay pavement. Faulting is observed to be sensitive to Subbase layer thickness in the case of overlay pavement. None of the rigid pavement performance indicators are sensitive to the Dowel Diameter and the base layer thickness for all the three pavement sections.

3.5 Flexible Pavement Structure Variation

For flexible pavements, the thickness of Layer1, materials used for Layer 2 and Layer 3(Base and Subbase) and PG Binder were varied while the rest of structure inputs were held fixed. The ranges of values for the input parameters that were varied were selected based on the recommendations of MEPDG and experts in the pavement section of WisDOT. As an example,

Table 3.13 shows the sensitivity of the various distresses to the change in Layer 1 thickness of the flexible pavements. The other variables were held constant at the base values.

Table 3. 13: Sensitivity Analysis of Flexible Pavement Performance to Changes in Layer 1 Thickness.

Layer 1	**IRI (in/mi)**	**L/C (ft/500)**	**A/C (%)**	**T/C (ft/mi)**	**PD(AC)(in)**	**PD(TP)(in)**
Distress Target Limit	< 172	< 1000	< 25	< 1000	< 0.25	< 0.75
8	140.5	1340	3.6	1	0.37	0.55
10	139.6	220	1	1	0.32	0.48
12	139.4	139	0.3	1	0.25	0.39

Ratio= $\frac{1340-139}{1000-0} * 100 = 120.1$ (Very Sensitive)

The complete results of the analysis are shown in Tables 3.14 and 3.15. The complete set of analysis outputs are included in Appendix A. These tables show the sensitivity analysis of performance indicators (IRI, L/C, A/C, T/C, PD(AC), PD(TP)) to the structure input parameters for two flexible pavement structures used. The structures included a conventional pavement and an overlay.

Table 3. 14: Conventional Flexible Pavement Structure Sensitivity

	Investigated Values	**IRI**	**L/C**	**A/C**	**T/C**	**PD(AC)**	**PD(TP)**
L 1 Thickness	8", 10",12"	I	VS	I	I	S	I
L 2 (Cr. Stone)	5", 10", 15"	S	VS	VS	I	VS	VS
L 2 (Cr. Gravel))	5", 10", 15"	S	S	VS	I	VS	VS
L 2 (A-1-b)	5", 10", 15"	S	VS	VS	I	VS	VS
L 3 (Cr. Gravel)	5", 10", 15"	I	I	I	I	I	I
L 3 (A-1-a)	5", 10", 15"	I	I	I	I	I	I
PG Binder	58-28,64-28,76-28,64-34,64-40	S	VS	VS	I	VS	S

Table 3. 15: Overlay HMA over HMA Structure Sensitivity

	Investigated Values	IRI	L/C	A/C	T/C	PD (AC)	PD(TP)
L 1 Thickness	8", 10", 12"	I	I	I	I	I	I
L 2 (Asp Concrete)	5", 10", 15"	I	I	I	I	S	S
L 2 (Asp Perm Base)	5", 10", 15"	I	I	I	I	S	S
L 3 (Cr. Gravel)	5", 10", 15"	I	S	I	I	S	I
L 3 (A-1-a)	5", 10", 15"	I	S	I	I	S	I
L 3 (A-1-b)	5", 10", 15"	I	S	I	I	S	I
L4(A-3)	5”, 10”, 15”	I	I	I	I	I	I
L4(A-4)	5”, 10”, 15”	I	I	I	I	I	I
PG Binder	58-28,64-28,76-28,64-34,64-40	I	I	I	I	I	I

From the sensitivity results and for the above investigated values, it can be seen that for flexible pavements IRI, L/C, A/C, PD(AC), PD(TP) are sensitive to most sensitive to the base layer thickness and PG Binder for the conventional pavement . It is also observed that PD (AC), PD (TP), L/C is sensitive to Base and Subbase layer thickness. None of the flexible pavement performance indicators are sensitive to the PG Binder and the Subbase layer thickness for the overlay pavement.

Chapter 4: Summary and Conclusions

The sensitivity of the performance of typical pavement sections used in Wisconsin to various traffic and pavement structure parameters was studied using the Mechanistic-Empirical Pavement Design Guide (MEPDG). More than 400 runs of the design software were conducted to determine the distresses and how they change when ceratin important variables are varied. Pavement performance included specific distresses as shown in Table 4.1 and Table 4.2, which gives the summary of the results in terms of sensitivity. Based on the results, the input parameters were ranked and categorized from parameters to which pavement performance is most sensitive to least sensitive (insensitive). The objective is to help pavement designers identify the level of importance for each input parameter and also identify the input parameters that can be modified to satisfy the predetermined pavement performance criteria. The following table provides the summary of trends observed.

Table 4. 1: Sensitivity of Pavement Performance to Traffic Input Variables

Traffic	**Rigid Pavement**			**Flexible Pavement**	
	Conventional	Stabilized base	Overlay JPCP Over JPCP	Conventional	Overlay HMA over HMA
AADTT	VS-cracking; S-faulting	S-IRI; VS-(faulting, cracking)	S-IRI; VS -(faulting, cracking)	VS- (L. Cracking, Perm Deform)	VS- Perm. Deform; S-Long. cracking
% Trucks	I	I	S-cracking	I	I
Traffic SD	I	S-cracking	S-cracking	I	VS-Perm. Deform
Traffic Speed	I	I	I	I	VS-Perm. Deform
Layer thickness	VS- IRI, Cracking and Faulting	NA	NA	VS- IRI, Cracking, Perm Deformation	NA

Note: VS – Very Sensitive; S – Sensitive; I – Insensitive

Table 4. 2: Sensitivity of Pavement Performance to Structure Input Variables

Traffic	Rigid Pavement			Flexible Pavement	
	Conventional	Stabilized base	Overlay JPCP Over JPCP	Conventional	Overlay_HMA over HMA
Thickness (L1)	VS-Cracking; S-IRI	S-Cracking	S-Cracking	VS- (L/C); S- (PD(AC))	I
L2, L3, L4 (Layers)	I	I	VS-Cracking, S-Faulting	VS-(L/C, A/C, PD(AC,TP)); S-IRI	S- PD(Ac), PD (TP), L/C
Joint Spacing	VS-Cracking	VS-Cracking	VS-Cracking	NA	NA
Dowel Diameter	I	I	I	NA	NA
Coeff. of thermal expansion	VS- IRI, Cracking and Faulting	VS-IRI, Cracking and Faulting	VS-IRI, Cracking and Faulting	NA	NA
PG Binder	NA	NA	NA	VS-L/C, A/C,PD(AC); S- IRI, PD(TP)	I

Note: VS – Very Sensitive; S – Sensitive; I – Insensitive

The analysis for rigid pavements shows that there are 3 main factors related to structure that can affect the performance indicators:

- Thickness of surface layer (concrete slab below 10 inches),
- coefficient of thermal expansion,
- joint spacing (for cracking)

In addition, in the special case of concrete overlay, the thickness of cement stabilized subbase layer appears to be important.

The analysis for the flexible pavement shows that the structure variables (type and thickness of layers) are very important for the performance. In general the following variables show the most effect on performance:

- Surface and base layer (L2), particularly for conventional structure,
- Subbase layer thickness (L3) is somewhat important for overlay designs.

It is clear that for flexible pavements the performance is much more sensitive to layer thicknesses than the rigid pavement structures. It is also noticeable that IRI is not very sensitive to the variables in both structures. This result is important in the sense that it gives a warning that IRI should not be considered as the main design criterion.

Based on the results of this study, pavement designers can identify the level of importance for each input parameter and also identify the input parameters that can be modified to satisfy the predetermined pavement performance criteria. It is expected that ranking could also help planners to determine how traffic of heavy vehicles could be directed to enhance the service life and ensure better maintenance strategies.

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Appendix A: Tables for Detailed Sensitivity Analysis – Flexible and Rigid Pavements

Sensitivity to Traffic Inputs

Rigid Pavements

Pavement Information:

1. **Conventional Pavement**

AADTT	1178
% trucks in the design lane	85
Operational Speed(mph)	70
Traffic Wander Standard Deviation	10
Vehicle Class Distribution	
Class 5	33.8
Class 6	33.8
Class 7	14.7
Class 9	16.2
Class 12	1.5

2. **Stabilized Base Pavement**

AADTT	1500
% trucks in the design lane	95
Operational Speed(mph)	60
Traffic Wander Standard Deviation	10
Vehicle Class Distribution	
Class 5	24.6
Class 6	7.6
Class 7	0.5
Class 9	31.3
Class 12	3.3

3. **Overlay JPCP over JPCP**

AADTT	3900
% trucks in the design lane	100
Operational Speed(mph)	60

Traffic Wander Standard Deviation	10
Vehicle Class Distribution	
Class 5	31.6
Class 6	9.1
Class 7	0.4
Class 9	39.3
Class 12	0.7

1. Conventional Pavement

	IRI(in/mi)	**% Cracking**	**Faulting(in)**
Distress Target	172	15	0.12

AADTT	**IRI(in/mi)**	**Cracking (%)**	**Faulting(in)**
1000	77.6	0.3	0.004
2500	82.4	1.4	0.012
5000	90.7	4.4	0.023
10000	107.8	13.1	0.042
Traffic SD	**IRI(in/mi)**	**Cracking (%)**	**Faulting(in)**
7	76.6	0.2	0.003
9	77.5	0.3	0.004
11	78.8	0.5	0.006
13	80.3	0.6	0.009
%Trucks	**IRI(in/mi)**	**Cracking (%)**	**Faulting(in)**
65	77.4	0.3	0.004
75	77.7	0.3	0.004
85	78.2	0.4	0.005
95	78.6	0.5	0.006
Op.Speed	**IRI(in/mi)**	**Cracking (%)**	**Faulting(in)**
45	78.2	0.4	0.005
60	78.2	0.4	0.005
75	78.2	0.4	0.005
90	78.2	0.4	0.005

2. Stabilized Base Pavement

	IRI(in/mi)	% Cracking	Faulting(in)
Distress Target	172	15	0.12

AADTT	**IRI(in/mi)**	**Cracking (%)**	**Faulting(in)**
1000	96.7	2.9	0.013
2500	113.9	12.4	0.03
5000	140.7	31.4	0.052
10000	178.1	59.9	0.079
Traffic SD	**IRI(in/mi)**	**Cracking (%)**	**Faulting(in)**
7	95.4	1.6	0.012
9	100	4.2	0.017
11	104.7	7	0.022
13	109.1	8.9	0.027
%Trucks	**IRI(in/mi)**	**Cracking (%)**	**Faulting(in)**
65	97.1	3.1	0.013
75	98.8	3.9	0.015
85	100.6	4.7	0.017
95	102.5	5.7	0.019
Op.Speed	**IRI(in/mi)**	**Cracking (%)**	**Faulting(in)**
45	102.5	5.7	0.019
60	102.5	5.7	0.019
75	102.5	5.7	0.019
90	102.5	5.7	0.019

3. Overlay JPCP over JPCP

	IRI(in/mi)	% Cracking	Faulting(in)
Distress Target	172	15	0.12

AADTT	IRI(in/mi)	Cracking (%)	Faulting(in)
1000	87.8	0.7	0.018
2500	100.9	3.1	0.04
5000	117.9	9.3	0.062
10000	144.1	24.6	0.088
Traffic SD	**IRI(in/mi)**	**Cracking (%)**	**Faulting(in)**
7	103.4	2.2	0.046
9	108.4	4.9	0.051
11	113.3	7.5	0.056
13	117.5	9.4	0.061
%Trucks	**IRI(in/mi)**	**Cracking (%)**	**Faulting(in)**
65	101.2	3.2	0.04
75	104.1	4	0.044
85	106.9	4.9	0.048
95	109.6	5.8	0.052
Op.Speed	**IRI(in/mi)**	**Cracking (%)**	**Faulting(in)**
45	110.9	6.3	0.054
60	110.9	6.3	0.054
75	110.9	6.3	0.054
90	110.9	6.3	0.054

Flexible Pavements

Pavement Information:

1. **Conventional Pavement**

Initial two-way AADTT	1178
Percent of trucks in design direction (%)	85
AADTT distribution by vehicle class	
Class 5	33.8
Class 6	33.8
Class 7	14.7
Class 9	16.2
Class 12	10
Traffic Wander Standard Deviation	10
Operation Speed(mph)	70

2. **Overlay HMA over HMA**

Initial two-way AADTT	2000
Percent of trucks in design direction (%)	95
AADTT distribution by vehicle class	
Class 5	24.6
Class 6	7.6
Class 7	0.5
Class 9	31.3
Class 12	8.3
Traffic Wander Standard Deviation	10
Operation Speed(mph)	60

1. Conventional Pavement

Distress Target	**IRI (in/mi)**	**L/Crack (ft/500)**	**A/Crack (%)**	**T/Crack (ft/mi)**	**P. Derm (AC) (in)**	**P. Derm (T.P) (in)**
	172	1000	25	1000	0.25	0.75
AADTT	**IRI(in/mi)**	**L/C(ft/500)**	**A/C (%)**	**T/C (ft/mi)**	**PD(AC)(in)**	**PD(TP)(in)**
1000	139.4	25.2	0.1	1	0.12	0.27
2500	139.4	101	0.4	1	0.19	0.35
5000	139.6	284	0.8	1	0.27	0.44
10000	139.9	905	1.9	1	0.39	0.57
% Trucks	**IRI(in/mi)**	**L/C(ft/500)**	**A/C (%)**	**T/C (ft/mi)**	**PD(AC)(in)**	**PD(TP)(in)**
65	139.5	136	0.5	1	0.21	0.38
75	139.5	169	0.6	1	0.23	0.39
85	139.5	204	0.7	1	0.24	0.41
95	139.6	240	0.7	1	0.25	0.42
Op. Speed	**IRI(in/mi)**	**L/C(ft/500)**	**A/C (%)**	**T/C (ft/mi)**	**PD(AC)(in)**	**PD(TP)(in)**
45	139.5	368	0.7	1	0.27	0.44
60	139.5	248	0.7	1	0.25	0.42
75	139.5	187	0.6	1	0.23	0.4
90	139.5	151	0.6	1	0.22	0.39
Traffic SD	**IRI(in/mi)**	**L/C(ft/500)**	**A/C (%)**	**T/C (ft/mi)**	**PD(AC)(in)**	**PD(TP)(in)**
7	139.6	243	0.8	1	0.26	0.43
9	139.5	217	0.8	1	0.25	0.42
11	139.5	188	0.9	1	0.23	0.4
13	139.5	162	1	1	0.22	0.39

2. Overlay HMA over HMA

Distress Target	**IRI (in/mi)**	**L/Crack (ft/500)**	**A/Crack (%)**	**T/Crack (ft/mi)**	**P. Derm (AC) (in)**	**P. Derm (T.P) (in)**
	172	1000	25	1000	0.25	0.75
AADTT	**IRI(in/mi)**	**L/C(ft/500)**	**A/C (%)**	**T/C (ft/mi)**	**PD(AC)(in)**	**PD(TP)(in)**
1000	75.5	40.3	0.3	0	0.19	0.39
2500	75.5	40.3	0.8	0	0.19	0.39
5000	76.2	447	1.9	0	0.42	0.67
10000	77.1	1190	4.3	0	0.58	0.87
% Trucks	**IRI(in/mi)**	**L/C(ft/500)**	**A/C (%)**	**T/C (ft/mi)**	**PD(AC)(in)**	**PD(TP)(in)**
65	75.5	64.7	0.4	0	0.22	0.43
75	75.6	80.3	0.5	0	0.24	0.46
85	75.6	97	0.5	0	0.25	0.47
95	75.7	149	0.6	0	0.27	0.49
Op. Speed	**IRI(in/mi)**	**L/C(ft/500)**	**A/C (%)**	**T/C (ft/mi)**	**PD(AC)(in)**	**PD(TP)(in)**
45	75.7	105	0.4	0	0.28	0.5
60	75.7	149	0.5	0	0.27	0.49
75	75.6	90.8	0.5	0	0.24	0.46
90	75.6	85.7	0.6	0	0.23	0.45
Traffic SD	**IRI(in/mi)**	**L/C(ft/500)**	**A/C (%)**	**T/C (ft/mi)**	**PD(AC)(in)**	**PD(TP)(in)**
7	75.7	138	0.7	0	0.28	0.5
9	75.6	108	0.6	0	0.26	0.48
11	75.6	87.6	0.5	0	0.25	0.47
13	75.6	72.2	0.4	0	0.24	0.45

Sensitivity to Structure Variables

Rigid Pavements

1. Conventional Pavement

Layer 1	JPCP
Thickness	10"
Layer 2	A-1-a
Thickness	3"
Layer 3	Crushed Gravel
Thickness	8"
Layer 4	SP
Thickness	NA
Joint Spacing	15'
Dowel Diameter	1.5"
Coeff of Thermal Exp.	5.2 per F^0*10^{-6}

2. Stabilized Base

Layer 1	JPCP
Thickness	8.2:
Layer 2	Cement Stabilized
Thickness	6.4"
Layer 3	A-1-a
Thickness	4.0"
Layer 4	A-2-4
Thickness	NA
Joint Spacing	15
Dowel Diameter	1.5
Coeff of Thermal Exp.	5.6 per F^0*10^{-6}

3. Overlay JPCP over JPCP

Layer 1	JPCP
Thickness	10.0"
Layer 2	Asphalt Concrete
Thickness	2.0"
Layer 3	JPCP(existing)
Thickness	9.9"
Layer 4	Crushed Stone

Thickness	4.0"
Layer 5	A-6
Thickness	NA
Joint Spacing	15
Dowel Diameter	1.125
Coeff of Thermal Exp.	5.5 per $F^{0}*10^{-6}$

1. Conventional Pavement

	IRI(in/mi)	**% Cracking**	**Faulting(in)**
Distress Target	**172**	**15**	**0.12**
L 1 Thickness (in)	**IRI(in/mi)**	**% Cracking**	**Faulting(in)**
8	119.3	30.1	0.032
10	79.9	0.8	0.008
12	76.2	0	0.006
L 2 (Cr. Stone) (in)	**IRI(in/mi)**	**% Cracking**	**Faulting(in)**
3	80.1	0.9	0.009
6	80.2	1.5	0.007
9	80.9	2.4	0.007
L 2 (Cr. Gravel) (in)	**IRI(in/mi)**	**% Cracking**	**Faulting(in)**
3	80.1	0.9	0.008
6	80.2	1.5	0.007
9	80.9	2.4	0.007
L 2 (A-1-b) (in)	**IRI(in/mi)**	**% Cracking**	**Faulting(in)**
3	78.9	0.4	0.006
6	78.6	0.4	0.006
9	78.7	0.5	0.006
L 3 (Cr. Gravel) (in)	**IRI(in/mi)**	**% Cracking**	**Faulting(in)**
10	79.8	0.7	0.008
15	79.8	0.8	0.008
20	79.6	0.6	0.008
L 3 (Cr. Stone) (in)	**IRI(in/mi)**	**% Cracking**	**Faulting(in)**
10	79.8	0.7	0.008
15	79.8	0.8	0.008
20	79.6	0.6	0.008
Joint Spacing (ft)	**IRI(in/mi)**	**% Cracking**	**Faulting(in)**
15	79.1	0.6	0.007
18	100.6	24.7	0.012
Dowel Diameter (in)	**IRI(in/mi)**	**% Cracking**	**Faulting(in)**
1.25	86	0.6	0.02
1.5	79.1	0.6	0.007
Coeff of Thermal Exp.	**IRI(in/mi)**	**% Cracking**	**Faulting(in)**
2.5	76.4	0	0.002
5	112.4	14.1	0.049
7.5	249.2	97.8	0.179
10	330.1	99.9	0.33

2. Stabilized Base

	IRI(in/mi)	% Cracking	Faulting(in)
Distress Target	**172**	**15**	**0.12**
L 1 Thickness (in)	**IRI(in/mi)**	**% Cracking**	**Faulting(in)**
8	94.4	5.6	0.012
10	88.5	0	0.01
12	87.2	0	0.008
L 2 (Lime Stab) (in)	**IRI(in/mi)**	**% Cracking**	**Faulting(in)**
3	94.3	2.3	0.017
6	92.2	2.2	0.014
9	90.7	3.4	0.009
L 2 (Soil Cement) (in)	**IRI(in/mi)**	**% Cracking**	**Faulting(in)**
3	94.3	2.3	0.017
6	92.2	2.2	0.014
9	90.7	3.4	0.009
L 2 (Lime Cemt Fly Ash) (in)	**IRI(in/mi)**	**% Cracking**	**Faulting(in)**
3	94.3	2.3	0.017
6	92.2	2.2	0.014
9	90.7	3.4	0.009
L 3 (Cr. Gravel) (in)	**IRI(in/mi)**	**% Cracking**	**Faulting(in)**
10	91.3	3.4	0.01
15	91.3	3.4	0.01
20	91.2	3.3	0.01
L 3 (Cr. Stone) (in)	**IRI(in/mi)**	**% Cracking**	**Faulting(in)**
10	91.3	3.4	0.01
15	91.3	3.4	0.01
20	91.2	3.3	0.01
Joint Spacing (ft)	**IRI(in/mi)**	**% Cracking**	**Faulting(in)**
15	92.4	3	0.013
18	112.7	24.7	0.021
Dowel Diameter (in)	**IRI(in/mi)**	**% Cracking**	**Faulting(in)**
1.25	92.4	3	0.013
1.5	90.1	3	0.008
Coeff of Thermal Exp.	**IRI(in/mi)**	**% Cracking**	**Faulting(in)**
2.5	87.8	0	0
5	91.2	0.9	0.005
7.5	139	46.3	0.025
10	202.4	97.5	0.066

3. Overlay JPCP over JPCP

	IRI(in/mi)	% Cracking	Faulting(in)
Distress Target	**172**	**15**	**0.12**
L 1 Thickness (in)	**IRI(in/mi)**	**% Cracking**	**Faulting(in)**
8	109.1	6.3	0.054
10	0	0.5	0
12	118.6	0	0.082
L 2 (Asph. Concrete) (in)	**IRI(in/mi)**	**% Cracking**	**Faulting(in)**
3	110.5	5.7	0.054
6	110.7	6.1	0.054
9	108.5	4.9	0.051
L 2 (Asph. Perm. Base) (in)	**IRI(in/mi)**	**% Cracking**	**Faulting(in)**
3	110.5	5.7	0.054
6	110.7	6.1	0.054
9	108.5	4.9	0.051
L 3 (Cement Stab) (in)	**IRI(in/mi)**	**% Cracking**	**Faulting(in)**
10	117	8.8	0.061
15	91.2	0	0.026
20	83.1	0	0.01
L 3 (Lime Stab) (in)	**IRI(in/mi)**	**% Cracking**	**Faulting(in)**
10	117	8.8	0.061
15	91.2	0	0.026
20	83.1	0	0.01
L 3 (Soil Cement) (in)	**IRI(in/mi)**	**% Cracking**	**Faulting(in)**
10	117	8.8	0.061
15	91.2	0	0.026
20	83.1	0	0.01
L 4 (Cr. Gravel) (in)	**IRI(in/mi)**	**% Cracking**	**Faulting(in)**
6	117.2	9	0.061
8	117.2	8.8	0.061
10	117.2	9	0.061
L 4 (A-1-a) (in)	**IRI(in/mi)**	**% Cracking**	**Faulting(in)**
6	117.1	8.8	0.061
8	117.1	8.8	0.061
10	117.1	8.8	0.061
Joint Spacing (ft)	**IRI(in/mi)**	**% Cracking**	**Faulting(in)**
15	117.2	9.1	0.061
18	130.3	22.5	0.078

Rigid Pavement Sensitivity – Structure

1. Conventional Pavement

	Investigated Values	**IRI**	**Cracking**	**Faulting**
L 1 Thickness	8", 10",12"	S	VS	I
L 2 (Cr. Stone)	3", 6",9"	I	I	I
L 2 (Cr. Gravel))	3", 6",9"	I	I	I
L 2 (A-1-b)	3", 6",9"	I	I	I
L 3 (Cr. Gravel)	10", 15", 20"	I	I	I
L 3 (Cr. Stone)	10", 15", 20"	I	I	I
Joint Spacing	15', 18'	I	VS	I
Dowel Diameter	1.25", 1.5"	I	I	I
Coeff of Thermal Exp.(per F*10^-6)	2.5, 7.5, 10	VS	VS	VS

2. Stabilized Base

	Investigated Values	**IRI**	**Cracking**	**Faulting**
L 1 Thickness	8", 10", 12"	I	S	I
L 2 (Lime Stab)	3", 6", 9"	I	I	I
L 2 (Soil Cement)	3", 6", 9"	I	I	I
L 2 (Lime C. F. A)	3", 6", 9"	I	I	I
L 3 (Cr. Gravel)	10", 15", 20"	I	I	I
L 3 (Cr. Stone)	10", 15", 20"	I	I	I
Joint Spacing	15', 18'	I	VS	I
Dowel Diameter	1.25", 1.5"	I	I	I
Coeff of Thermal Exp. (per F*10^-6)	2.5, 7.5, 10	VS	VS	VS

3. Overlay

	Investigated Values	IRI	Cracking	Faulting
L 1 Thickness	8", 10", 12"	I	S	I
L 2 (Asp Concrete)	3", 6", 9"	I	I	I
L 2 (Asp Perm Base)	3", 6", 9"	I	I	I
L 3 (Cement Stab)	10", 15", 20"	I	VS	S
L 3 (Lime Stab)	10", 15", 20"	I	VS	S
L 3 (Soil Cement)	10", 15", 20"	I	VS	S
L 4 (Cr. Gravel)	6", 8",10"	I	I	I
L 4 (A-1-a)	6", 8",10"	I	I	I
Joint Spacing	15', 18'	I	VS	I
Dowel Diameter	1.25", 1.5"	I	I	I
Coeff of Thermal Exp. (per F*10^-6)	2.5, 5, 7.5, 10	VS	VS	VS

Note: S - Sensitive, I – Insensitive, VS – Very Sensitive

Flexible Pavements

1. Conventional Pavement

Layer 1	Asphalt Concrete
Thickness	10"
Layer 2	A-1-a
Thickness	12"
Layer 3	Crushed Stone
Thickness	15"
Layer 4	SP
Thickness	NA
PG Binder	70-22

2. Overlay HMA over HMA

Layer 1	Asphalt Concrete
Thickness	4"
Layer 2	Asphalt Concrete(existing)
Thickness	5"
Layer 3	Crushed Stone
Thickness	7.4"
Layer 4	A-6
Thickness	12"
Layer 5	A-7-5
Thickness	NA
PG Binder	64-22

1. Conventional Pavement

Distress Target	**IRI (in/mi)**	**L/Crack (ft/500)**	**A/Crack (%)**	**T/Crack (ft/mi)**	**P. Derm (AC) (in)**	**P. Derm (T.P) (in)**
	172	1000	25	1000	0.25	0.75
L1 Thickness(in)	**IRI(in/mi)**	**L/C(ft/500)**	**A/C (%)**	**T/C (ft/mi)**	**PD(AC)(in)**	**PD(TP)(in)**
8	140.5	1340	3.6	1	0.37	0.55
10	139.6	220	1	1	0.32	0.48
12	139.4	139	0.3	1	0.25	0.39
L2 Cr. Stone	**IRI(in/mi)**	**L/C(ft/500)**	**A/C (%)**	**T/C (ft/mi)**	**PD(AC)(in)**	**PD(TP)(in)**
5	139.9	679	1.9	1	0.31	0.48
10	139.9	805	1.9	1	0.31	0.48
15	210.2	10600	76.4	1	0.6	0.94
L2 Cr. Gravel	**IRI(in/mi)**	**L/C(ft/500)**	**A/C (%)**	**T/C (ft/mi)**	**PD(AC)(in)**	**PD(TP)(in)**
5	139.9	679	1.9	1	0.31	0.48
10	139.9	805	1.9	1	0.31	0.48
15	210.2	10600	76.4	1	0.6	0.94
L2 A-1-b	**IRI(in/mi)**	**L/C(ft/500)**	**A/C (%)**	**T/C (ft/mi)**	**PD(AC)(in)**	**PD(TP)(in)**
5	139.9	702	2	1	0.31	0.48
10	139.4	85.3	0.4	1	0.13	0.3
15	210.2	10600	76.4	1	0.6	0.94
L3 Cr. Gravel	**IRI(in/mi)**	**L/C(ft/500)**	**A/C (%)**	**T/C (ft/mi)**	**PD(AC)(in)**	**PD(TP)(in)**
5	140	766	2.1	1	0.3	0.49
10	139.9	769	2	1	0.31	0.49
15	139.9	861	1.9	1	0.31	0.48
L3 A-1-a	**IRI(in/mi)**	**L/C(ft/500)**	**A/C (%)**	**T/C (ft/mi)**	**PD(AC)(in)**	**PD(TP)(in)**
5	140	759	2.1	1	0.3	0.49
10	139.9	760	2	1	0.31	0.48
15	139.9	855	1.9	1	0.31	0.48
PG Binder	**IRI (in/mi)**	**L/C(ft/500)**	**A/C (%)**	**T/C (ft/mi)**	**PD(AC)(in)**	**PD(TP)(in)**
58-28	144.8	10100	16.9	1	0.31	0.59
64-28	117.9	0	0.1	1	0.11	0.3
76-28	117.8	0	0.1	1	0.11	0.3
64-34	120.4	0	0.2	1	0.16	0.36
64-40	121.5	0	0.2	1	0.18	0.39

2. Overlay HMA over HMA

Distress Target	IRI (in/mi)	L/Crack (ft/500)	A/Crack (%)	T/Crack (ft/mi)	P. Derm (AC) (in)	P. Derm (T.P) (in)
	172	2500	25	2500	0.4	0.5
L1 Thickness	**IRI(in/mi)**	**L/C(ft/500)**	**A/C (%)**	**T/C (ft/mi)**	**PD(AC)(in)**	**PD(TP)(in)**
8	75.3	1.4	0.2	0	0.15	0.33
10	75.3	0.4	0.1	1	0.12	0.28
12	75.3	1.6	0	1	0.13	0.27
L2 Asp Conc	**IRI(in/mi)**	**L/C(ft/500)**	**A/C (%)**	**T/C (ft/mi)**	**PD(AC)(in)**	**PD(TP)(in)**
5	75.6	115	0.6	0	0.27	0.49
10	75.5	1.2	0.2	1	0.12	0.29
15	75.4	9.4	0.2	1	0.13	0.27
L2 Asp Perm	**IRI(in/mi)**	**L/C(ft/500)**	**A/C (%)**	**T/C (ft/mi)**	**PD(AC)(in)**	**PD(TP)(in)**
5	75.6	115	0.6	0	0.27	0.49
10	75.5	1.2	0.2	1	0.12	0.29
15	75.4	9.4	0.2	1	0.13	0.27
L3 Cr. Gravel	**IRI(in/mi)**	**L/C(ft/500)**	**A/C (%)**	**T/C (ft/mi)**	**PD(AC)(in)**	**PD(TP)(in)**
5	75.7	839	0.7	0	0.26	0.49
10	75.6	122	0.6	0	0.27	0.49
15	75.6	63.6	0.6	0	0.27	0.49
L3 A-1-a	**IRI(in/mi)**	**L/C(ft/500)**	**A/C (%)**	**T/C (ft/mi)**	**PD(AC)(in)**	**PD(TP)(in)**
5	75.7	878	0.7	0	0.26	0.49
10	75.7	165	0.6	0	0.27	0.49
15	75.6	79.5	0.6	0	0.27	0.49
L3 A-1-b	**IRI(in/mi)**	**L/C(ft/500)**	**A/C (%)**	**T/C (ft/mi)**	**PD(AC)(in)**	**PD(TP)(in)**
5	75.7	879	0.7	0	0.26	0.49
10	75.7	141	0.6	0	0.27	0.49
15	75.6	74.2	0.6	0	0.27	0.49
PG Binder	**IRI (in/mi)**	**L/C(ft/500)**	**A/C (%)**	**T/C (ft/mi)**	**PD(AC)(in)**	**PD(TP)(in)**
58-28	77.4	118	0	1	0.2	0.25
64-28	76.7	106	0	1	0.18	0.24
76-28	75.9	90.4	0	1	0.17	0.22
64-34	77	117	0	1	0.19	0.24
64-40	77.4	133	0	1	0.2	0.26